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December 1971

GRAPHICAL MAN/MACHINE COMMUNICATIONS
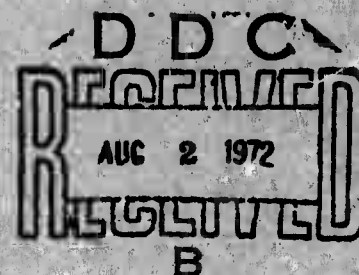
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13. ABSTRACT

This document includes a summary of research activities and facilities at the University of Utah under Contract F30602-70-C-0300.   Information conveys important research milestones attained during this period by each of the four major research activities:

1 - Computer Graphics Techniques

2 - Computing Systems

3 - Digital Waveform Processing

4 - Applications

Details of illustrations in
this document may be better
studied on microfiche

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KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
animation						
audio waveforms						
color vision						
computing systems						
DISMOL (Display of Molecular Structure)						
display processor						
elastic systems						
graphic techniques						
homomorphic deconvolution						
kinematic systems						
partial differential equations						
seismic data processing						
shading						
three-dimensional computer models						
waveform processing						

GRAPHICAL MAN/MACHINE COMMUNICATIONS

David C. Evans

Principal Investigator: David C. Evans
                 Phone: 801 322-8224

Project Engineer: Murray Kesselman
                 Phone: 315 330-2643

PUBLICATION REVIEW

This technical report has been reviewed and is approved.

RADC Project Engineer

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PART I. SUMMARY OF RESEARCH ACTIVITIES

The objective of the graphical man/machine communication effort is the development of computers and computing techniques that people may use interactively in real time to extend their problem-solving capability, and to work cooperatively by means of improved communications via computer.

The following summary of research activities is included for general information. Detailed descriptions about specific research projects are contained in the body of the report.

Graphic Techniques

Gary Watkins is currently building a hardware processor to solve the hidden line problem at 30 frames per second. The processor acts as a peripheral unit to the PDP-10, using the memory of the PDP-10 as storage for the data structure. The output is to be displayed on a CRT as a shaded half-tone picture. Reliability tests are being conducted at present by the PDP-10, comparing data from the software algorithm and the hardware processor.

A procedure for computing shaded pictures of curved surfaces was recently developed by Henri Gouraud. The surface is approximated by small polygons in order to solve easily the hidden-parts problem, but the shading of each polygon is computed so that discontinuities of shade are eliminated across the surface, and a smooth appearance is obtained. In order to achieve speed efficiency, the technique developed by Watkins is used, which makes possible a hardware implementation of this algorithm.

In most of the earlier computer generated pictures, there has been an objectionable step-like character given to the boundary between visible surfaces. This phenomenon is more severe than that seen with digitized photographs and television. It is particularly objectionable in motion pictures. The cause is that a computer generated picture raster element is based on a point sample calculation rather than integration over the projected area of the object corresponding to the picture raster element. New shading algorithms solving this problem have been developed and tested, and produce pictures of greatly improved appearance; these are incorporated in the equipment which is now being tested.

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Waveform Processing

Research in waveform processing continues under the direction of
Thomas G. Stockham, Jr. A paper has been written which concisely
describes the eight identifiable forms of distortion associated with
the use of analog to digital and digital to analog converters in
processing analog signals. Work has begun to further crystallize the
thoughts presented in this paper, and to produce an audio tape which
will demonstrate the various forms of distortion for subjective eval-
uation. This work is valuable for setting guidelines with respect to
converter quality when considering such problems as speech recognition
and computer assisted physophysical testing in the field of hearing.

Experiments are currently taking place which are attempting to
adapt the methods of homomorphic deconvolution (as applied to the
restoration of old acoustic recordings) to the problem of eliminating
blur from photographs. The benefit of this method over others which
may already be known is that it is applicable even in those cases in
which the blur is caused by an unknown camera motion or type of lens
defocus, and there is no test object within the image from which these
unknowns can be deduced. Experiments have progressed to the point
where computer simulations have shown that the method is capable of
deducing the blurring mechanism from the blurred photograph itself,
and to the point where encouraging restorations have been made from
these estimates.

A homomorphic speech analysis and synthesis system, which is
capable of detecting a voice pitch and vocal tract characteristics,
has been constructed and checked out. This system is being formed
in preparation for an experiment which will attempt to remove back-
ground noise from, and reconstruct lost frequency components in record-
ings of the human voice. Experiments with old recordings are being
used as a vehicle for this work.

A system for the synthesis of audio waveforms, especially those of
a musical nature, is nearing completion. This system is designed to
serve a dual purpose: first, it will allow a quantitative study of
information rates required to produce sounds of substantial sophisti-
cation; second, it will allow the study of those ingredients which make
sounds interesting and therefore compatible with the human hearing
system, so as to better understand the mechanism of the latter. As a
test to see whether or not this program is capable of producing a spec-
trum of sounds of sufficient complexity and interest, a brief musical
concert is being prepared from it.

Preliminary steps have been made to discover to what extent the
theories of multiplicative processing, which we have previously applied
to black and white photography and vision, can be extended to include

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the aspect of color. So far, the effort has been limited to the calibration of our precision display for use with various color recording materials and to simple experiments which demonstrate the classical color illusions, such as simultaneous color contrast.

Graphic Modeling

Henry N. Christiansen has been working on a continuing exploration of computer graphics techniques as they apply to the analysis of kinematic and elastic systems. Two main aspects of his work are: the creation of a simulator for kinematic and elastic systems, and the utilization of computer graphics software and hardware to produce continuous tone images.

Interest is centered about the application of computer graphics to understand medical phenomena in research headed by Harvey Greenfield. Problems emphasized are the movement of blood through natural and prosthetic heart valves and blood flow through various vascular channels so as to understand the formation of atherosclerotic lesions.

Symbolic and Algebraic Manipulation

This research, under the direction of Anthony Hearn, is aimed toward the development of effective techniques for the solution of a wide range of symbolic and algebraic problems, and is oriented to both computer software development and the use of the developed programs in solving practical problems, primarily using the REDUCE system.

Switching Theory

Areas of switching theory research being explored by Charles Seitz are: a new algorithm for generating fault-detection or checking experiments for synchronous sequential circuits; new results, relating the probability of synchronizer fault with synchronizing frequency, circuit bandwidth, and noise power; and asynchronous design techniques based on the "m-net" have been extended to include race-free implementations using Muller C-elements.

A. COMPUTER GRAPHIC TECHNIQUES

The senior investigators in computer graphics techniques are David C. Evans (faculty), Ivan E. Sutherland (faculty), Ronald D. Resch (faculty), and Robert E. Stephenson (faculty). The primary goal of the research is the development of graphics techniques for the realistic dynamic display of three-dimensional objects.

Two aspects to this research are: (1) the techniques for picture generation from numerical models, and (2) development of languages, input devices, and other tools required to specify and manipulate models and pictures.

Over the past five years, our effort has been concentrated on modeling representation, picture generating algorithms, and machinery. Although much work remains to be done in this area, the art has advanced sufficiently so that the most pressing work now is the graphic input and language problem. Emphasis is placed upon the capability of the user to interact with the structured data representation of the object being viewed by the graphic system, rather than emphasizing the graphic system as a picture generator by itself.

1. DISPLAY PROCESSOR

We are endeavoring to build a complete real-time picture making facility of which the conceptually new component is the Watkins Processor.

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The main components of the Watkins processor are now operating. However, much remains to complete the facility including work on the matrix multiplier, polygon clipper, halftone shader, and display and photographic equipment in order to make this resource available to the researchers who are developing new language and manipulation techniques.

Individual algorithms and components have all been demonstrated, and have proved that the display processor can be done. Much work remains. The task now is to get all parts assembled in terms of a workable operating system for the researchers to use. The head-mounted display will be integrated into the system.

Watkins Processor

Gary Watkins is currently building a hardware processor to solve the hidden line problem at 30 frames per second. The processor acts as a peripheral unit to the PDP-10, using the memory of the PDP-10 as storage for the data structure. The output is to be displayed on a CRT as a shaded half-tone picture. Reliability tests are being conducted at present by the PDP-10, comparing data from the software algorithm and the hardware processor. The scope driver of the shader (the unit that will display the intensity point information on the scope) has been designed and is 75% completed.

Arbitrary Painting of Three-Dimensional Computer Models

There are some new processes of picture generating techniques that we are working on. In the past, the models have been built geometrically of surfaces represented by polygonal patches. The object painting has been simply related to the geometrical structure of the model in the sense that each polygonal patch has been painted uniformly, i.e., it has uniform color, reflection, and scatter properties. In order to make more realistic looking models, it is desirable to separate the painting from the geometry because very large computational tasks (Watkins processor) are associated with the geometry processing.

At present there are two research activities in painting:

(1) A continuous color shading across polygonous patches.

A more versatile method of "coloring computer generated images using Gary Watkin's hidden line algorithm[1] and Henri Gouraud's smooth shading program[2], has been studied. By specifying colors for the vertices of object-describing-polygons, a new technique was developed which permits objects to be "colored" without being entirely restricted within the bounds of specific polygons. This results in an unlimited range of colors and patterns, thus allowing a more realistic imitation of the real world.

An attempt is being made at a practical application of computer-generated-picture techniques in the area of human anatomy. Currently, studies are being made of the human inner and middle ear to gather data in order to build a "computer mockup" of the ear to study and demonstrate the functions of its various structures.

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(2)   The use of polygonal painting of single geometrical patches by the multitude of polygon paint patches on the geometrical patch, as if the geometrical patch were painted by multiple layers of paint in the same way many objects are painted in real life.

> The current procedure to make pictures of complex coloring is to define many polygons, each having a single color. This procedure often needlessly complicates the hidden surface algorithm. It is hoped that the increase in time of processing a polygon will be offset by decreasing the time of the hidden surface algorithm by reducing the number of overlapping polygons.

2.   GRAPHIC LANGUAGES

The means by which the user of the computer modeling and picture generating system controls and produces the models to make the desired pictures are all part of the graphic languages business. For economy of communications, we have adopted the term "animation" for this activity.

Several animation language systems are being developed, ranging from the specialized language called DISMOL, which is a language for specifying chemical molecular structures in animation, to more general purpose languages including a generalization of APL and two more general purpose animation languages.

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In one of them, a great deal of work has been done on the subject of dynamically changing objects and shapes. Applications for the development of this language are shown in Figure 1.

This work especially emphasizes the data representation and the associated transformation matrices for specifying the trajectories and motion in complex systems. Particular applications used in this development are the maneuvering and landing of aircraft as shown in Figure 2.

Dismol (A System for the Display of Molecular Structure and Motion)

Following our successful production of a computer generated motion picture of molecular structure and motion, the Chemical Engineering Department at the University of Utah has produced a new data describing molecular behavior of a complexity which has heretofore escaped man's conceptual grasp. With the aid of computer programs for the display of molecular motion, it is possible to accurately depict and observe this behavior. In addition, data describing the complete quantum mechanical behavior of ethane is forthcoming, and should prove equally enlightening. A major hindrance has been the absence of a working link between the Univac 1108, where the data is generated, and the PDP-10, where the motion pictures are generated. This problem is apparently solved, however.

An animated film showing the actions of a soma cube has also been produced. This film shows the soma cube assembling, gyrating, and breaking up into a number of different shaped configurations. These films were produced in full color, and the objects displayed were in three-dimensional
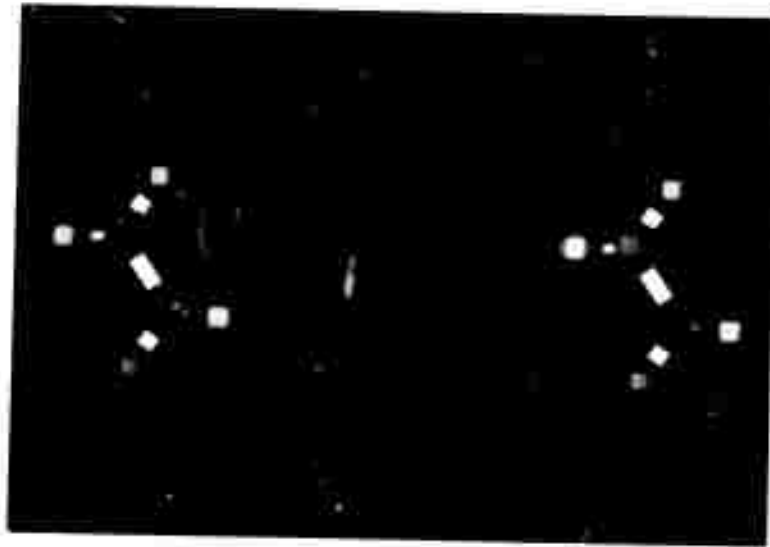
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Figure 1: DISMOL

Figure 2: Aircraft Landing

shaded image form. We are continuing to extend these applications.
We have also investigated the control of color in shaded images, and
have some preliminary results from this investigation, although addi-
tional work yet needs to be done.

APL with Graphics

APLG (A Programming Language with Graphics) extends APL to include
graphics on an interactive basis, and presents the user with powerful
capabilities to display and manipulate graphical output. In weaving a
graphics package into APL, special care was taken to preserve the
aesthetic qualities of the language and make use of the existing opera-
tors and basic data structures. Since APL is basically suited to graphics,
only a few new primitives and system commands are required to unveil a
whole new realm of possibilities. Two areas of user interest are con-
sidered: (1) display and manipulation of mathematical waveforms, and
(2) display and transformation of user defined objects. Descriptions
of all pictures to be displayed on the screen are contained in display
matrices over which the user has complete control to create, change, and
manipulate, giving him unusual power to mold objects into desired forms.
Information from the display screen may be entered into the system by way
of the mouse and applied advantageously as various circumstances arise.
The new primitives which allow graphical input-output and facilitate the
creation of display matrices, as well as the new graphics-related system,
are described in a readily understandable manner. Numerous trivial and

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sophisticated examples illustrate practical applications and suggest potential possibilities for APLG. APL is already a good system; but with the addition of interactive graphics, the new system is even better.

Distorting Surfaces

This is an investigation of a technique for producing computer generated animated films of objects that deform or change shape. The objects maintain the same topology throughout the deformation. Films were produced of a three-dimensional block letter H changing into an airplane, and of a face changing expression. The face films show a face going from sober to surprised, from surprised to smiling, and from sober to smiling as shown in Figure 3 . This film has been produced in black and white and some attempts have been made to extend the technique to color images.

Animation Language

Three projects are being developed simultaneously:

1. A program is being developed for accepting three-dimensional polygonal objects and manipulating them. This program is now working. The object used for testing is a representation of a hand (Figure 4). The program accepts instructions that bend fingers of the hand. (Other kinds of relational changes can be made that do not apply to a hand.)

Figure 3: Changing Face

Figure 4: A sequence
of 5 frames showing
the hand open and close.

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2. An interpreter has been written for a language that generates instructions for the above program. For instance, one may specify for an object to move (or rotate) to a position from frames n through m. The percent of change made in each frame can be specified according to an arbitrary table or function, i.e., the object can accelerate. The interpreter has been written but not debugged.

3. A language has been designed for apparent parallel processing of routines This will provide a natural system for specifying actions that occur concurrently.

Input Devices

3-D Wand -- Efforts are under way by which a person can make a position in 3-D and make strokes and otherwise give manual commands in 3-D to the system. This is an extension of the generally well-understood 2-D graphical input device patterned after the Rand tablet.

The head-mounted display[3] is used in combination with a 3-D hand-held input device (wand) for "drawing" and altering three-dimensional "synthetic objects" which are visible only to the user of the display. The position of the wand will be tracked by mechanical, ultrasonic, and sonic methods and the three methods will be compared. To date, the wand has been made operable with ultrasonic tracking, and it has been used to alter the shape of synthetic objects.

A System for the Measurement of Moving Objects in 3-D (Twinklebox) -- A single electro-mechanical scanner-sensor designed to determine the

feasibility of using multiple one-dimensional scanner-sensors together with light-emitting diodes in the measurement and display of moving objects has been tested. The results obtained are satisfactory and encouraging. The design of the associated electronics has been investigated in some depth, and arrangements have been made with the Instrumentation Research Laboratory of the Electrical Engineering Department of the University of Utah for assembly of the electronics and construction of the scanner-sensors.

An algorithm has been written for the determination of the positions and orientations of objects observed by the scanner-sensors. Work has begun on a program to orient objects accordingly. Techniques have been developed to allow the user to move the scanner-sensors around the room (for greater accuracy, a larger field, a different point of view, etc.), and then operate immediately without having to determine the new positions of the scanner-sensors. An associated data structure for computer animation has been developed.

3. RESEARCH IS CONTINUING IN TWO ADDITIONAL AREAS:

    a. Interaction of the picture structure with the raster structure.

    b. Pictures in limited visability situations such as fog and low ambient light.

B. COMPUTING SYSTEMS

This research group, directed by Charles Seitz, has as its common interest real computing systems with radically improved characteristics for direct use by people, such as: communication devices, simulation and modeling devices, and computational instruments. Emphasis is not primarily on raw computational capacity, but rather on system problems of the direct use of these machines by people in a natural way, so that procedures may be easily described and information may be simply represented.

Line-drawing Display

The goal of this project is to rebuild the Harvard three-dimensional display, using a combination of commercial processing elements (E&S LDS-1 channel control and matrix multiplier), a clipping divider rebuilt from the ruins of the Harvard version, and a new scope and sorting box driver. It is hoped that this effort will:

(1) make the system sufficiently reliable and rational that users will reappear, and well enough organized internally to serve as a "testbed" for new hardware.

(2) allow the computational capabilities of this line-drawing display to be used to preprocess (interpret structure, rotate, clip, and place into perspective and a suitable coordinate system) images for the halftone processor.

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The evolution of the system since its design and successful operation at Harvard has included attempts to interface it to different control processors. The original organization routed most data through a central "big buffer," which was quite adequate as an interface to a PDP-1, and later a PDP-9 at Utah. When it was later interfaced to the PDP-10, a new set of control logic was devised to drive the old control. Then when interfaced to an LDS-1 channel control, still more control was overlayed. By this time, the system had lost its ability to "pipeline," and had become very unreliable and incredibly irrational from the programming standpoint.

During 1971, there were several meetings of the graphics researchers to decide what to do with this equipment. The proposal to obtain an E&S matrix multiplier and clipping divider was rejected, since it was generally felt that the E&S clipping divider could not provide some features necessary to drive the half-tone hardware, and would be very difficult to modify. However, the group felt that the E&S matrix multiplier provided a degree of reliability, and important programmatic features (such as multiple matrices, matrix concatenation, automatic curve drawing) not attainable with the Harvard matrix multiplier. Also, with the matrix multiplier interfaced between the E&S channel control and a clipping divider (providing an 80-bit interface in the correct format for the clipping divider input), the redesign of the clipping divider would be much simplified. Thus it was decided to buy a new-style matrix multiplier, and to rebuild the clipping divider section of the Harvard display, using parts from the Harvard matrix multiplier and kludge controls.

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This decision was the starting point for this project. The purchase of the matrix multiplier has been repeatedly delayed by contractual problems, but the other parts of the project -- the restructuring of the system, and new interface conventions, physical dismantling and rebuilding, and the detail logic design and some construction of the new system is now under way.

The dismantling of the Harvard matrix multiplier, big buffer, etc., was completed in August. A new scope interface was designed and built in August and September. The gross redesign of the clipping divider, including the addition of a data-buffered output (which operates with a separate asynchronous control) and a redefinition of the clipper's output interface was completed in September. It is expected that these changes will nearly double the speed of the clipping divider. A new microprogrammed control element for the clipper is currently being designed. It will employ field-programmable ROM's, which should permit easy incorporation of new algorithms for proper clipping of polygons.

Switching Circuits Laboratory

While a state-supported facility, the switching circuits laboratory is currently being used by ARPA-supported graduate research assistants doing special projects.

(a) EDSACII -- We are building a bit-serial computer using the instruction set and internal register structure of Wilkes' EDSAC, but using modern components. The main store of the machine is implemented with MOS shift registers, rather than mercury tanks, for example, but the

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logical characteristics of EDSAC II should be similar to those of the original (1949) EDSAC. In addition to its historical value and interest, the comparison of the performance characteristics of EDSAC II, using a 1947 architecture with modern machines, makes an interesting comparison. The program library for EDSAC (published in Wilkes, Wheeler, and Gill, 1952) will be usable on EDSAC II as well.

(b) Asynchronous circuits -- The laboratory has been used to test several theoretical results concerning (1) the design of asynchronous circuits using Muller C-elements rather than delays to eliminate races, (2) direct implementation of Petri-nets from C-elements and RS flip-flops, and (3) the "hangup" phenomenon and the "after-you" phenomenon as asynchronous arbiters and flip-flop synchronizers.

Switching Theory

Of some interest here are:

(1) A new algorithm for generating fault-detection or checking experiments for synchronous sequential circuits, presented at the International Symposium on the Theory of Machines and Computations, Haifa, August 1971.

(2) Some apparently new results, relating the probability of synchronizer fault with synchronizing frequency, circuit bandwidth, and noise power. These results are currently being written up in formal style for publication, and have been partly verified experimentally.

(3) Asynchronous design techniques based on the "m-net" have been extended to include race-free implementations using Muller C-elements. This has not as yet been written up and published.

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C. WAVEFORM PROCESSING

Research in waveform processing continues under the direction of Thomas G. Stockham, Jr. A paper[4] has been written which concisely describes the eight identifiable forms of distortion associated with the use of analog to digital and digital to analog converters in processing analog signals. Work has begun to further crystallize the thoughts presented in this paper and to produce an audio tape which will demonstrate the various forms of distortion for subjective evaluation. This work is valuable for setting guidelines with respect to converter quality when considering such problems as speech recognition and computer assisted physophysical testing in the field of hearing.

Deblurring

Investigation is proceeding into a general method for restoration of two-dimensional signals which have been degraded by convolution with an arbitrary unknown degradation function. When implemented, this research will allow restoration of motion- or focus-blurred pictures much more quickly and accurately than present cut-and-try methods.

The method to be used is that of generalized linear filtering. Picture blur cannot be removed by ordinary linear filtering, which can only separate components that have been combined by addition. As stated, picture blur is a result of convolutional combination of a picture with

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a degrading function. However, a series of two transformations exists which will carry the convolutional combination of picture and blur into a space where the picture and blur are added. This series of two transformations is the two-dimensional Fourier Transform followed by the complex logarithm. Since the log spectrum of the result is the sum of the log spectra of the picture and that of the blur, subtraction of an estimate of the picture log spectrum will leave an estimate of the blur log spectrum. The blur function or its inverse can thus be recovered. An estimate of the picture log spectrum can be obtained from an unblurred picture with the same characteristics as those that appear to be contained in the blurred picture.

The method is presently in the process of implementation. Degradations with no phase have been estimated very accurately. Degradations with small amounts of phase can be estimated with some accuracy at present.

Goals of this project at present include estimation of degradations with large phase, and comparison of the results of this method with those of the cut-and-try method at its best. Closed form generation of log spectra for estimation purposes and the general topic of properties of two-dimensional log spectra will also be investigated.

Color Vision Modeling and Color Picture Processing

This research effort is addressed to the problem of modeling color vision as a three-channel system, and processing color images as three-dimensional signals.

Several researchers have shown that the early stage of achromatic vision can be satisfactorily modeled as a logarithmic transformation followed by a convolution (i.e. a linear spatially invariant system). These results are supported by ample psychological and physiological evidences, and more specifically, the assumption of a convolution process is in harmony with the established notion of lateral inhibition in the neural network of the retina. The investigations were based on the study of visual illusions and perception phenomenons such as Mach Bands, brightness contrast, and brightness constancy.

Following our previous approach to understanding black and white vision by digital computer modeling[5], our intent is to develop an advanced three-receptor model of color vision. Within this framework, a color image is considered as a three-dimensional signal constituted of three primary images (blue, green, red). We plan to investigate the validity of a model composed of a logarithmic transformation stage followed by a three-input, three-output linear stage, where each output is a combination of linear transformations of each input. Again, the assumption of convolution processes seems consistent with the notion of neural interaction between the three types of color receptors in the retina; the experimental basis of this research will be provided by the study of color contrast and color constancy illusions, which stress dramatically the interaction of colors in the perception world.

This research is by now at the stage of technical adjustment of the image producing equipment (CRT, LENS, etc.), and of early programming and preliminary perception experiments.

A further development could be the enhancement of real color pictures, using what will be learned about the interactions of color sensations.

Digital Processing of Images

An investigation into methods for producing digital images of the highest possible quality has been started. The primary thrust of the inquiry at present involves an exploration of methods for conveniently compensating the nonlinearity of photographic materials. The approach attempts to categorize the Hurter-Driffeld curve, relating photographic density to log exposure by a simple parametric family of functions. Given a description of typical photographic materials, it should be possible to compensate a digital image for the nonlinear photographic processes used in sensing or display. At the same time, the goal is to make the family of compensating functions simple to understand and easy to use.

Bandwidth Reduction of Audio Signals via Parameter Transmission

The standard bit rate for transmission of high quality audio signals is approximately a quarter of a million bits per second. The principle of transmitting waveform parameters as a basis for communication might eventually result in high quality transmission requiring only hundreds of bits per second. In contrast with other efforts of this nature, our effort does not concentrate exclusively on speech. In this

regard we are designing a system for the synthesis of audio waveforms, especially those of a musical nature, which is nearing completion. This system is designed to serve a dual purpose: first, it will allow a quantitative study of information rates required to produce sounds of substantial sophistication; second, it will allow the study of those ingredients which make sounds interesting and therefore compatible with the human hearing system, so as to better understand the mechanism of the latter. As a test to see whether or not this program is capable of producing a spectrum of sounds of sufficient complexity and interest, a brief musical concert is being prepared from it.

Audio Processing

At present, this research project is concerned with the extraction of vocally produced sounds (speaking and singing), from signals with background noises. This task is to be accomplished by synthesizing the human voice sounds present in the signals by utilizing a vocoder.

The vocoder under consideration represents a mathematical model of the vocal tract as a time varying, linear system. The set of parameters describing the vocoder is highly dependent upon the position of the vocal tract at any particular time and is relatively independent of the noise environment in which the vocal tract exists. In addition, the inputs to the vocoder are restricted to pulses, representing puffs of air applied to the vocal tract during voiced speech, and to white noise, representing a stream of air applied to the vocal tract during voiceless speech.

Since the human vocal tract changes position slowly, the total state of the vocoder is represented as a sequence of state variables, each of which varies only slowly in time. During each small time interval, the state of the vocoder, i.e. the set of parameters that describe the vocally produced sound over that time interval, is estimated from the noisy signal. In addition, a vocoder synthesis is performed from these parameters. Since the state of the vocoder is relatively immune to the noise environment in which the voice exists, the sounds produced by the vocoder synthesis should be relatively free of background noises.

This project began in June 1971 and has proceeded to the point where the vocoder has attained the desired high speech quality, and the estimation of the state of the vocoder and vocoder synthesis have been automated. Initial experiments indicate that the method works well for mild but distracting background sounds, but so far experience is limited.

D. APPLICATIONS

The applications area includes a small set of carefully selected problem areas that will provide feedback to the researchers in the first three research categories, and will provide a mechanism for publication of newly learned techniques to people outside the relatively closed community of computer science researchers.

Involved in the applications activity are Henry N. Christiansen (faculty), Harvey S. Greenfield (faculty), Anthony C. Hearn (faculty) and Louis A. Schmittroth (adjunct professor). Applications are in the field of computer-aided design, techniques for solving mathematical problems, the modeling of complex geometrical structures, and the modeling of a collection of fluid-flow problems (including the flow of blood in the human circulatory system). These problems are in the main supported jointly by the University of Utah and other agencies including the National Institutes of Health; hence this work does not represent an unreasonable fraction of the total resources.

Symbolic and Algebraic Manipulation

This research is directed toward the development of effective techniques for the solution of a wide range of symbolic and algebraic problems; it is oriented to both computer software development and the use of the developed programs in solving practical problems.

Most of the work of this project concerns the development of the REDUCE[6] system for algebraic simplification and its use in solving practical problems. Considerable progress has recently been made in the preparation of the whole REDUCE program in its own language, and we plan to distribute it in this form by the end of this year. As we are committed to making REDUCE as exportable as possible, we believe that the successful completion of this step will enable a much larger class of users to understand how the program works. Previous distributions have been made in the LISP programming language.

The power of the program has recently been enhanced by the inclusion of a new algorithm for calculating greatest common divisors of polynomials. This algorithm is many times faster than those previously available. It was implemented by Dr. Rüdiger Loos of this group, and is the first example of a part of the REDUCE system which was programmed completely in the REDUCE language rather than being first written in LISP. Dr. Loos plans to implement a factorization algorithm and an integration package in REDUCE in the near future. We also plan to distribute the new gcd algorithm by the end of this year.

Several important applications of REDUCE during the recent past have been made by people working outside our group. For example, researchers at the Max Planck Plasma Physics Institute in Munich, Germany, have recently proved analytically the existence of linear instabilities in a toroidal plasma. This work could have important consequences for the design of Tokamak-like controlled fusion devices.

Kinematic and Elastic Systems

The original purpose of this study was to develop a computer program which would simulate the kinematic and elastic behavior of foldable plate and truss structures. The more recent purpose has been to explore possibilities for displays of the output of the simulator and other finite element programs.

The requirement for the simulator was generated by Resch[7], who created what he terms "kinematic folded plate systems." The common property of these systems is that, by allowing only folding along the edges of a continuous line pattern, a flat sheet may be transformed into a variety of three dimensional shapes. These systems give promise of the mass production of non-identical structures of unusual beauty and structural efficiency.

The functions of kinematic and elastic analysis were accomplished as a result of a finite element stiffness approach to the linear elasticity problem. Developments which allow this approach include the modeling of the folds as elastic hinges and the generation of applied

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force systems which tend to restore the original dimensions of the elements.

Upon completion of the simulator, effort was directed toward the utilization of the ability to produce continuous tone pictures to display the stress, strain and displacement results of the finite element solutions producible with the simulator and other programs. Three methods of data presentation were devised and developed. In the most primitive mode, the object is displayed under load, and variation of the light intensity of the surface of the objects utilized to indicate the level of stress or strain. A variation on this scheme results from making the light intensity proportional to the square of a harmonic function of the selected stress or strain component. In this way, fringe effects develop which have a character much like that produced using photo-elastic techniques. In another scheme, the object is warped such that the out of plane coordinate is proportional to the stress or strain function. The resulting three-dimensional shape is displayed in a conventional manner.

Displays of Elastic Systems - One compelling attraction of the photo-elastic technique is that it allows the analyst the opportunity to "see the stresses." With the thought that this benefit might be made available to finite element users, a study was launched into possible schemes for the presentation of stress, strain and/or displacement data available in a discrete digital format.

It was apparent that displacement data could readily be displayed in the form of a continuous tone picture of a highly distorted structure. The problem, then, centered upon ways to superimpose stress or strain information on the distorted geometry. Three methods have, so far, emerged from this effort. The first two involve the variation of the light intensity of the surface to indicate the stress or strain level. The third involves geometry modifications to accomplish the same purpose. Each method has, so far, only been applied to plane stress problems.

In each method, the data may be displayed in a "flat" or "smooth" manner. The "flat" presentation preserves the identification of the individual elements by "painting" the entire element the same average light intensity. "Smooth" shading utilizes the recently developed curved surface capability to create the illusion of continuous stress or strain variations. This is accomplished by employing linear interpolation to the light intensities computer for each corner node. In each of the pictures presented in this section, both formats are shown.

To facilitate these two formats, the elastic analysis capability of the simulator was modified in two ways. First, a quadrilateral element (composed of four constant strain triangular elements) was introduced. This element is more convenient with respect to automatic grid generation and provides relief from the grid bias problem. Second, the procedure utilized to calculate element stress and strain was changed. In order to achieve node values instead of element values, the standard procedure of premultiplying the displacement vector by stress matrices was replaced

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by a least square fit routine. This procedure allows the prediction of strain components as a result of "fitting" the node displacement components with an incomplete cubic polynomial in the in-plane coordinates. The function, based upon a local coordinate system, is

$$u_i = a_{i1} + a_{i2}x + a_{i3}y + a_{i4}x^2 + a_{i5}xy + a_{i6}y^2 + a_{i7}x^2y + a_{i8}xy^2 \ .$$

The "fit" is applied to a local set of nine nodes.

Black to White Shading - The initial scheme involved the shading of the elements according to the magnitude of the stress or strain component selected for presentation. Elements with a high value appear bright (i.e. highly reflective) and those with a low value appear relatively dark.

Experimentation suggests this to be a good procedure whenever high gradients are involved. For this reason, the method is useful in the display of beam problems. For these simulations, the most effective function for display is maximum shear stress (or strain). This function allows the combined display of the bending moments and shear diagrams. At the neutral-axis, the maximum shear stress is equal to the absolute value of the shear stress on the cross-section and thus (at least for uniform beams) proportional to the shear diagram. At the top and bottom fibers, where shear stress on the cross-section and the lateral normal stress components are both zero, the maximum shear stress is equal to one-half the absolute value of the axial stress component, and thus monitors the bending moment diagram.

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Figure 5 illustrates the "flat" and "smooth" shading of a uniform beam with "built-in" end conditions. The model, containing 504 quadrilateral elements, was assigned a modulus of elasticity of 28 million psi and Poisson's ratio of 0.25. The desired level of displacement was achieved by the specification of the displacement magnitude of the quarter span location. By scanning along the upper or lower edge of the beam, four changes in sign of the bending moment diagram can be observed. Repeating the scan along the neutral axis shows uniform shear with abrupt changes in sign at the three load locations (indicated by computer generated arrows). The "smooth" shaded picture, especially, suggests a local drop in the maximum shear stress under the one-quarter span loads. This is because the axial and lateral stress components are both approximately the same negative value, which results in a small value for the maximum shear stress. At mid-span the lateral and axial stress components are unequal and a local maximum is observed.

Fringe Patterns - A modest change in the "black to white" scheme results in the display of fringe patterns. The effect is not unlike experimental stress optic patterns, but has the advantage that the user may display the stress or strain component of his choice. The modification is to display a new function, ϕ, instead of the stress, σ, where

$$\phi = \cos^2(\alpha\sigma+\beta)$$

The constants α and β are chosen so as to select a particular number of fringes and to shift the pattern.
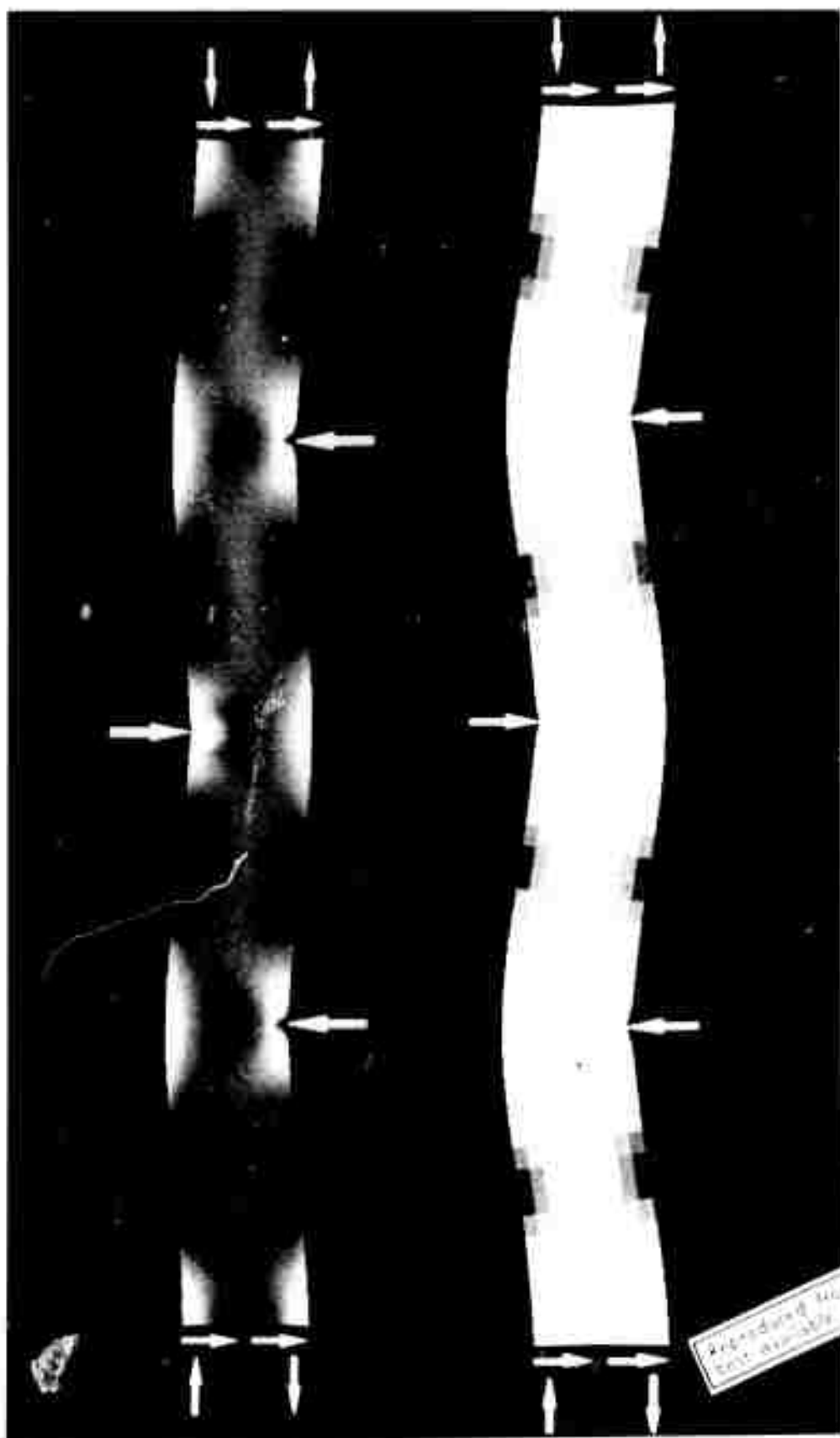
Figures 6 and 7 illustrate this technique applied to the analysis of thin plate configurations. In both examples, the modulus of elasticity is 1 million psi, Poisson's ratio is 0.45, and there are two axes of geometrical and loading symmetry. The function displayed is the maximum principal stress.

Figure 6 is a perspective representation of a rectangular (45 by 30 inch) plate with a circular hole (diameter 15 inches). The model contains 800 quadrilateral elements. The axial load varies from 66,700 psi at the center, to zero at the outer edges. A complete shading cycle (white to black to white) represents a stress change of 50,000 psi.

Figure 7 illustrates a perspective view of a strip containing a circular ring section. The overall length is 8.4 inches, the width at the end is 2.4 inches, and the diameter of the hole is 3.5 inches. The model contains 840 elements. The loading is a uniform axial stress of 20,000 psi. In this picture, a complete shading cycle represents a stress change of 75,000 psi.

The main drawback in this format is the lack of identification of the stress level associated with any particular fringe. That is, if one scans from white to black, he may not know if the stress level has increased or decreased. Further, if he continues the scan into a new white zone, has he changed fringes? Color variation in parallel with light variation is currently being investigated as a possible solution to this problem.

A similar effect has recently been achieved by Sanford[8], who produced computer generated holographic interference patterns for known
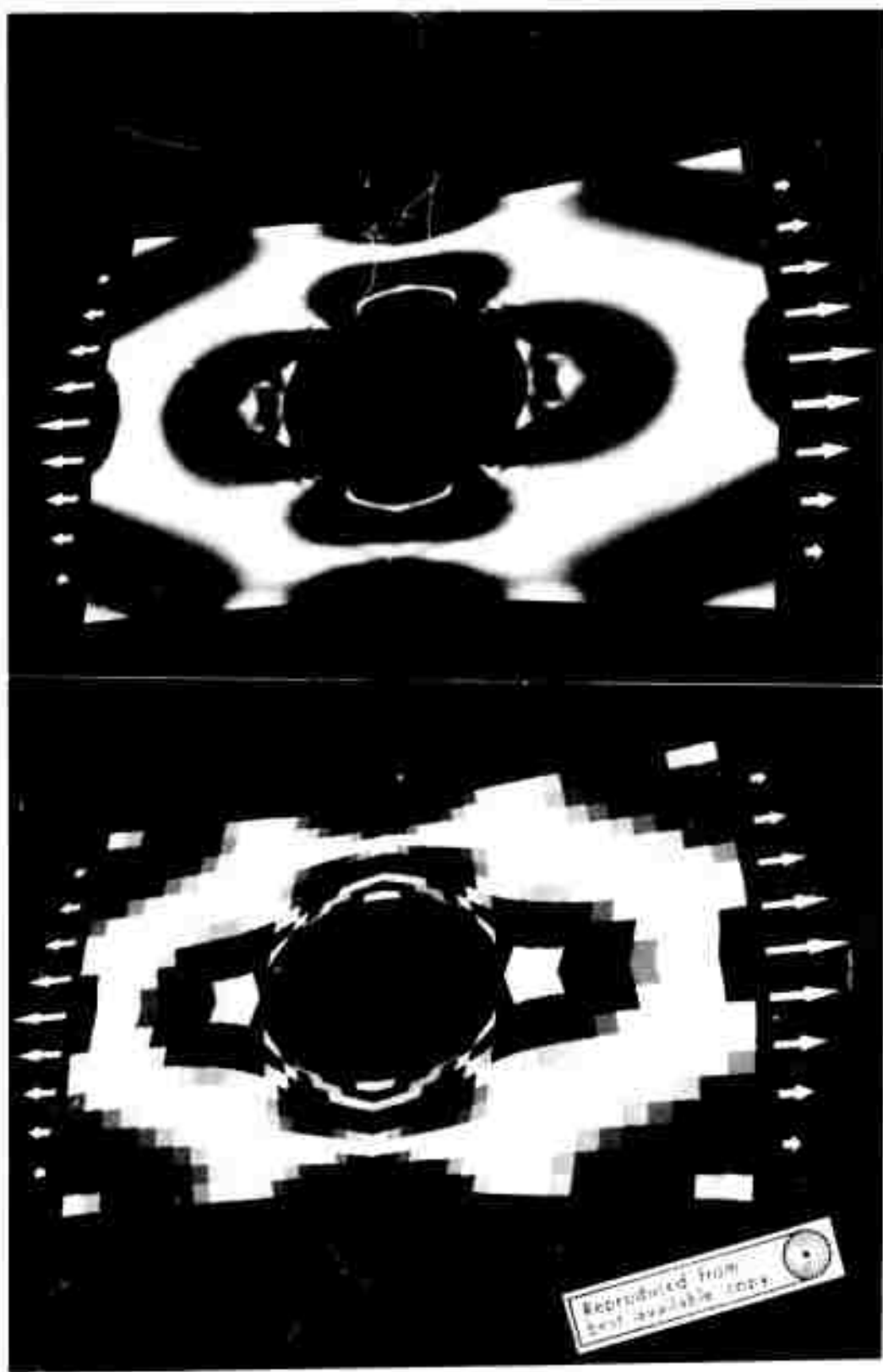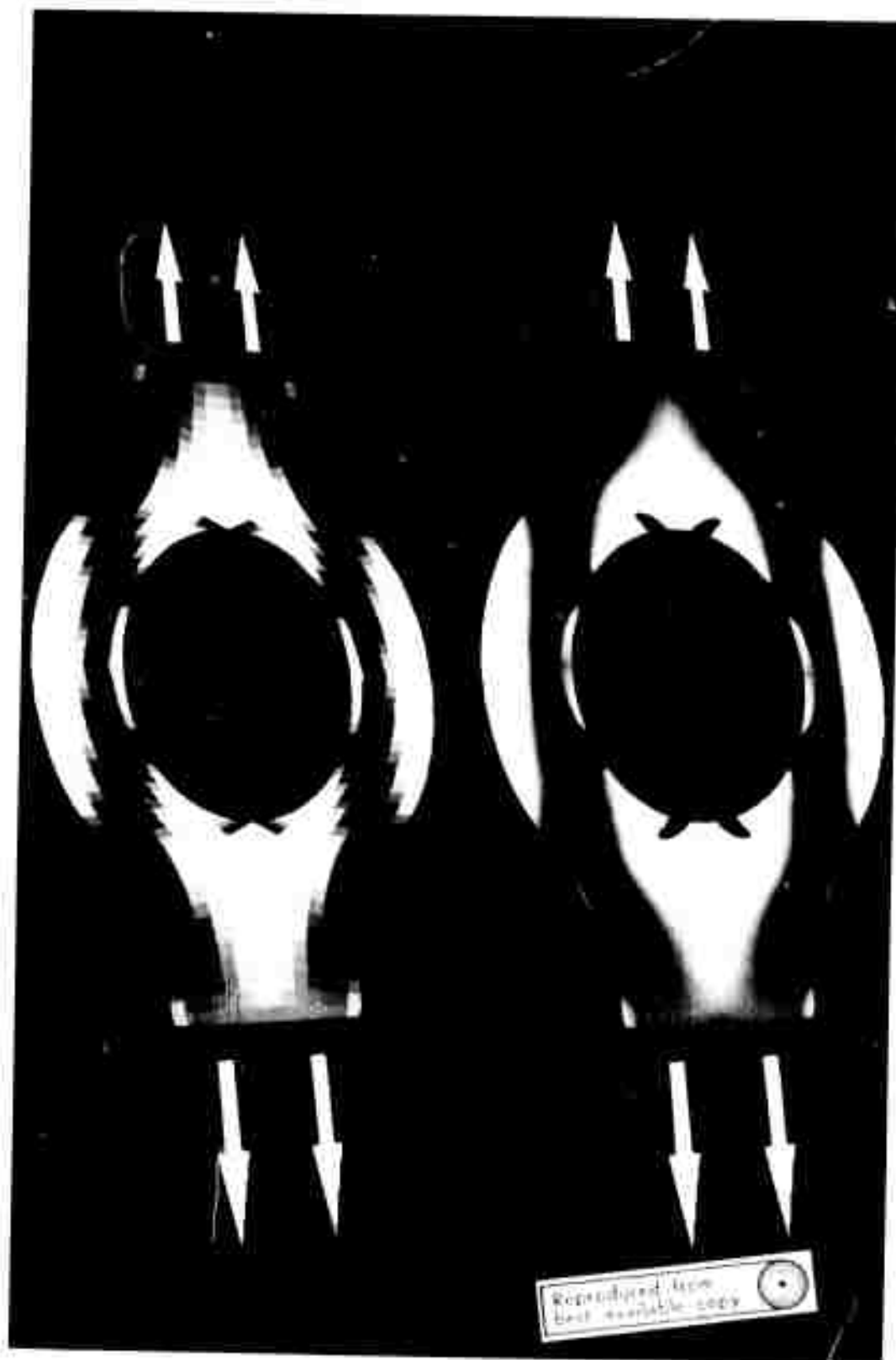
Figure 6: Plate with Median ...

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theoretical stress solutions. His patterns are shown in the undistorted geometry. An interesting contrast with Sanford's work is that, with closed form solutions, the analyst may ask for more fringes and (until the fringe width approaches the resolution of the equipment), he gets them. However, with finite element results, to ask for a large number of fringes usually results in a random pattern that looks much like a very poor quality Navajo rug.

Warped Surfaces - The previously described display formats utilized variation in the light intensity of the surface to describe a chosen stress or strain function. An alternate procedure is to introduce geometry modifications in the form of computed out of plane coordinates which are proportional to the stress or strain function. This seems natural, as functions of two variables are often displayed as a surface whose height above the reference plane is proportional to the function. Light variation is also utilized, but now to indicate the angle between the normal to the surface and the direction to the illumination source (the eye of the observer). For "flat" shading, the element normal is chosen as the average of the four normals computed on the basis of vector products of the adjacent sides. This average normal is also the normal obtained by the vector product of the diagonals of the quadrilateral. For the "smooth" shading version, the least square fit routine is again utilized to obtain normals at each node.

Figures 8 and 9 illustrate this display format for the problems previously discussed and displayed in a fringe effect format in figures 6 and 7.

In viewing this display form, the observer is acutely aware of the apparent stress concentrations (perhaps for the first time). While stress concentrations and sharp gradients do occur in these regions, the shapes displayed are dependent upon the local element definition and behavior of the least square fit procedure as utilized to generate strain values.

Comparing the "flat" and "smooth" shading versions, in the vicinity of the stress concentrations, suggests that very good definitions of curved surfaces may be developed from rather crude models. This is generally true. However, several drawbacks are also apparent. If this were the only display format available, each picture would have to be accompanied by an undistorted picture to describe the geometry. Further, it is difficult to find a satisfactory viewing angle and magnitude of distortion. The problem is somewhat compounded by the errors made by the hidden surface routine in the form of small holes in the surface. These errors apparently arise from difficulties the routine has in treating highly warped quadrilateral elements in a complex hidden surface environment.

It is expected that this form of display will come into its own when movies are made showing the transition from the undistorted to distorted geometry and allowing the observer to see the surface from many angles.

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Figure 9: Strip with Circular Ring Section

Usage to date suggests that a repeated linear analysis which employs the concept of corrective forces is an effective way to solve kinematic problems. Indeed, rapid convergence to an exact result has been the usual experience. Nevertheless, a greater potential is envisioned for the display techniques. Even here, the most likely occurrence is the development of superior methods of presentation as opposed to the adoption of these procedures.

Large Scale Numerical Studies

The task of solving large scale numerical problems with the aid of computer graphics systems has centered about the solutions to Navier-Stokes equations. This is a system of nonlinear partial differential equations for which exact solutions are allowed for only a few special cases. These equations are within the major areas of application of modern applied mathematics since they exhibit all the computational difficulties of other systems of partial differential equations of mathematical physics. With the aid of computer graphics, numerical solutions to the equation system now seem within reach.

The task is two-fold; forming required computer algorithms for display purposes from the numerical techniques employed, and applying the algorithms to a set of significant problems. As mentioned in the past, hemodynamic problems have been chosen with emphasis upon studying blood flow through prosthetic heart valves and also forming knowledge concerning the formation of atherosclerotic lesions. The application studies are funded by a National Institutes of Health grant.

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Within the time period covered by this report, a large report[9] was finalized which described past studies of concern to two-dimensional studies. Three-dimensional studies have continued wherein flow investigations have employed a simplified Marker and Cell technique for satisfying free surface boundary conditions. This approach has led to employment of an arbitrary Boundary Marker and Cell method. The numerical analysis is understood and certain basic algorithms have been formed. Application-wise, it will allow the insertion of a major step for duplicating flow over objects that undergo large deformations or move about within the computational mesh. Such objects include flexing leaflets of a heart valve and a pulsing arterial wall.

In turn, steady flow through an abrupt expansion in a tube to an annular region is being viewed in order to determine the proper cage length for a prosthetic heart valve. Also being pursued part time is the analysis of a jet impinging upon a non-rigid plate. The step beyond this is to consider non-sinusoidal oscillatory of the jet with subsequent structural weakening of the assumed elastic plate. Such steps are preparatory to viewing and understanding damage to an artery with the aid of a computer display screen.

Realizing that there is a steep shear stress gradient within the blood portion that is enclosed as the ball in a prosthetic heart valve moves closer to the confining cage struts, this action is being analyzed. That area between an enlarged portion of the arc formed by a section of the ball's surface and an enlarged strut is currently being studied by

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the development of stress equations for blood flow in the area. Interesting surface and perspective view plots have been seen on the graphics display screen.

In another sub-project, the University of Utah Computer Science Department's head mounted display system was employed to form movement through an idealized aorta section. With rotation of parameters, the user theoretically "walked" through the aorta, turned and "walked" through a renal artery. In turn, the observer was moved through a simplified ball-type prosthetic heart valve. Motion was employed so as to have the internal viewing continue through the sewing ring of the valve. Some particular time frame results from a short film are shown in Figures 10 and 11. The future significance of this project is that all other projects mentioned previously will be combined with this one. Thus, two- and three-dimensional studies, the stress analysis investigation, the jet impinging upon an elastic plate study, etc., together would allow the observer on a "fantastic voyage" to walk through an artery section and see a lesion grow, or walk into a heart valve and see the blood flow in a theoretical fashion. Varying conditions and assumptions could be quickly interchanged for evaluating many human circulatory system phenomena.

In a rare attempt to verify computer graphics results, scattered-light photo stress equipment has been built with NIH funds. Internal stress valves for the ball-type prosthetic heart valve have been formed in a preliminary fashion. As this study progresses, equivalent theory computer formulations of stress lines will be compared and algorithms formed will thus have experiment based verification.
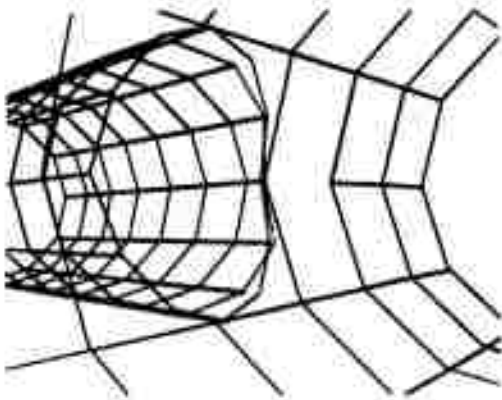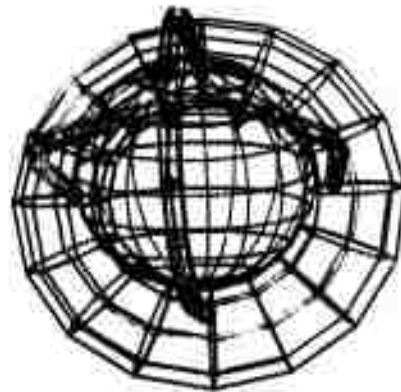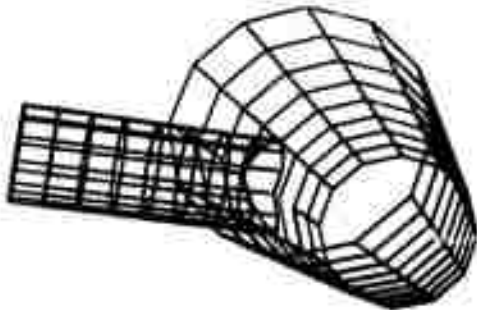
Figure 10. Some Views of the Vascular Channel Configuration as Formed by Computer and Studied with the Aid of the Head-Mounted Display System. In Bottom Figure, Observer is within Large Artery and Looking into the Renal Artery.

Figure 11. Some Views of a Typical Ball-Type Prosthetic Heart Valve as Formed by Computer and Studied with the aid of the Head-Mounted Display System. In Bottom Figure, Observer Has Passed Through the Sewing Ring.

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Seismic Data Processing

Seismic refraction data representing over 360 traces were recorded along a 350 km profile in the Middle Rocky Mountains. These data were recorded in an FM mode from large quarry blasts to investigate the possibility of low velocity zones and to determine the fine structure of the crust. These data were originally recorded in an FM mode and later digitized on a 14 bit A to D converter at the University of Wisconsin.

Special subroutines have been developed to transmit these data in ASCII and twos-compliment binary, 24 bit formats on the University of Utah UNIVAC 1108 to a 36 bit format on disc packs at the PDP-10 installation.

In order to interpret these seismic data, new waveform processing techniques are required to increase the coherent signal-to-noise ratio through bandpass filtering, predictive deconvolution, homomorphic deconvolution, ray tracing, and data modeling.

An important new method in seismic data processing is inverse modeling. In this technique, a functional representation of the travel-times and amplitudes of seismic rays propagating through the earth has been programmed on the PDP-10 time-sharing system. These theoretical data in two dimensions (x,z) are displayed on the interactive CRT, along with observed field data, for immediate judgement by the interpreter. The idealized earth model is then perturbed through one or more of several variables (compressional or shear wave velocities, layer configuration,

layer thickness, etc.), via the interactive subroutines and the new theoretical response is redisplayed.

Three seismic refraction profiles have been initially interpreted for fine crustal structure with these routines. Because of the immediate display of complex data sets and the ability of the interpreter to make more comprehensive judgements, the data have been interpreted with more meaningful results, and with a reduction in computer time of several hours over normal computer operations.

In addition, complex seismic ray tracing has been developed for the interactive time-sharing system. This technique allows the introduction of complex earth structure with two-dimensional digitized velocity functions. Because of the highly non-linear time-distance variation, control and adjustment of the reflecting and refracting rays has been accomplished through user interactive control at a CRT-teletype terminal. Because of the complex data and program structure, human interaction has produced the logical and economical programming path that might not otherwise be possible to program in a batch mode.

The next step in our interpretational plan is to apply rectilinear and homomorphic filtering to large sets of the seismic data, which will be displayed in a time-distance mode on the storage CRT's with filter development and program control accomplished at the interactive terminal.

PART II. FACILITIES

Computer Facilities

During this period, the TENEX software and hardware has been installed, and is now being used as the standard system on the PDP-10 time-sharing system.

There have been no major changes in the computer hardware configuration, but due to increased levels of research, more memory is being seriosly considered for the future. Figure 12 shows an up-to-date layout of the computing facilities.

Photographic Laboratory

Construction of a new photographic facility was completed during this period. The new facility is designed to expedite a variety of photographic requirements without the necessity of tear-down and set-up as existed with the previous lab. The new lab is approximately 50% larger, and will increase the efficiency of operation and permit a greater ability to work with and exploit new photographic methods as may be required, including motion picture processing.

Waveform Processing "Quiet Room"

A new "quiet room" required by the waveform processing research group was completed late in this period. The room adjoins the PDP-10

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computer room, and will be used for conducting experiments in sound
and measurements in psychophysics. Specialized construction techniques
and materials were necessary to obtain the required acoustical prop-
erties of Noise Criteria N.C. 15.

PART III.   PUBLICATIONS AND PRESENTATIONS

1 June 1971 to 31 December 1971

Following is a listing of presentations and publications
made by Computer Science Department personnel during the reporting
period related to ARPA sponsored projects and/or activities.   This
listing is included merely to indicate the scope of exposure our
work has had during this period and not as a means of announcing
new research discoveries made under the contract.   All significant
information contained in either the presentations or written articles
has been previously reported on an individual basis.

Bennion, Scott T.   A Method of Solution for Hydrodynamics and
    Radiation Diffusion as a Multi-Material Problem in One
    Dimension,   University of Utah Computer Science Technical
    Report UTEC-CSc-71-114,   June 1971.

Greenfield, H. S.,   'Computer Graphics Usage for Artificial Organs"
    luncheon lecture for IEEE Salt Lake Chapter,   November 1971.

Greenfield, H. S., "Shear Stress Analysis and Hemolysis by Computer Graphics" lecture to Materials Science-Applied Mathematics (National Science Foundation Student Training Program), Salt Lake City, Utah, August 5, 1971.

_____, "Innovations of Concern to Medical Research" lecture to Exchange Club, Salt Lake City, Utah, November 17, 1971.

_____, and W. Kolff, "The Prosthetic Heart Valve and Computer Graphics" Journal of the American Medical Association (Special articles) 31 December 1971, pages 69-74.

_____, and R. DeBry, An Application of Computer Graphics: Two Concurrent Investigations within the Medical Field, University of Utah Computer Science Department Technical Report UTEC-CSc-71-115, November 1971.

_____, and K. Reemtsma, "Preliminary Analysis of Blood Flow Characteristics in the Abdominal Aorta by Computer Interpretation" Computer Graphics in Medical Research and Hospital Administration, (eds. Parslow and Green) Plenum Press, New York, 1971, pages 35-55.

Hearn, A. C., "Calculation of Traces of Products of Gamma Matrices" paper presented at the Colloquium on Advanced Computing Methods in Theoretical Physics, CNRS, Marseilles, June 21-25, 1971. (To be published in the Proceedings of this Colloquium).

_____, "The Computer Solution of Algebraic Problems by Pattern Matching" paper presented at the Colloquium on Advanced Computing Methods in Theoretical Physics, CNRS, Marseilles, June 21-25, 1971. (To be published in the Proceedings of this Colloquium).

_____, "Applications of Symbol Manipulation in Theoretical Physics" paper presented at the Seminar Course on Computing as a Language of Physics, International Centre for Theoretical Physics, Trieste, Italy, August 2-20, 1971. (To be published in the Proceedings of this Seminar).

_____, "Polynomial Manipulation by Computer" paper presented at the Seminar Course on Computing as a Language of Physics, International Centre for Theoretical Physics, Trieste, Italy, August 2-20, 1971. (To be published in the Proceedings of this Seminar).

_____, "Symbolic Analysis for Physical Theories Represented by Diagrams" paper presented at the Seminar Course on Computing as a Language of Physics, International Centre for Theoretical Physics, Trieste, Italy, August 2-20, 1971. (To be published in the Proceedings of this Seminar).

Kelsey, S. J. and E. B. Christiansen, "Isothermal and Nonisothermal Laminar Tube-Entrance Flow of Despersions" presented at the International Symposium of Two Phase Flow at Haifa, Israel Summer 1971.

Seitz, C. L., "An Approach to Designing Checking Experiments Based on a Dynamic Model" Theory of Machines and Computations, Academic Press, New York and London, 1971.

Stockham, T. G., Jr., "The Importance of Non-Linear Enhancement in Visual Prosthesis Design" Visual Prosthesis the Interdisciplinary Dialogue, Academic Press, New York, 1971, pages 173-192.

_____, "A-D and D-A Converters: Their Effect on Digital Audio Fidelity" 41st Convention of the Audio Engineering Society, October 1971, Preprint No. 834.

_____, "Restoration of Old Acoustic Recordings by Means of Digital Signal Processing" 41st Convention of the Audio Engineering Society, October 1971, Preprint No. 831.

_____, "Image Processing in the Context of a Visual Model" talk given at a short course entitled Computer Processing and Recognition of Two Dimensional Images, University of Southern California, Los Angeles, California, July 1971.

_____, "Practical Considerations in Scanning High Quality Images Into and Out of Digital Processors" talk given at the 1971 Picture Coding Symposium, Perdue University, October 1971.

_____, "More Sophisticated Image Models" talk given at the 1971 Picture Coding Symposium, Perdue University October 1971.

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1. Gary S. Watkins, "A Real-Time Visible Surface Algorithm," Univ. of Utah Technical Report, UTEC-CSc-70-101, June 1970.

2. Henri Gouraud, "Computer Display of Curved Surfaces," Univ. of Utah Technical Report, UTEC-CSc-71-113, June 1971.

3. Donald L. Vickers, "Head-Mounted Display Terminal," Proc. of 1970 IEEE International Computer Group Conference, June 16-18, 1970, Washington, D.C.

4. Thomas G. Stockham, Jr., "A-D and D-A Converters: Their Effect on Digital Audio Fidelity," presented at the 41st Convention of the Audio Engineering Society, October 5, 1971 (preprint number 834).

5. Thomas G. Stockham, Jr., "Intraframe Encoding for Monochrome Images by Non-Linear Filtering," Picture Bandwidth Compression, (eds. Thomas S. Huang and Ohl J. Tretiak), Gordon and Breach, Science Publishers, 1972.

6. Anthony C. Hearn, "REDUCE - A Program for Symbolic Algebraic Computation," Invited Paper presented at SHARE XXXIV, Denver, Colorado, March 2-6, 1970.

7. Ronald D. Resch and Henry N. Christiansen, "The Design and Analysis of Kinematic Folded Plate Systems," Proc. Symposium for Folded Plates and Prismatic Structures, International Association for Shell Structures, Vienna, Austria, October, 1970.

8. R. J. Sanford and A. J. Durelli, "Interpretation of Fringes in Stress-Holo-Interferometry," Experimental Mechanics, Vol. 11, April, 1971, pp. 3-8.

9. Harvey Greenfield and Roger DeBry, "An Application of Computer Graphics: Two Concurrent Investigations within the Medical Field," Univ. of Utah Technical Report, UTEC-CSc-71-115, November, 1971.